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## **Middle Power Measurement in Semi-tethered Swimming using Ergometer Attachment**

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## Middle Power Measurement in Semi-tethered Swimming using Ergometer Attachment

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The purposes of this study were to measure middle power, energy which had been supplied mainly from the lactic acid system, during swimming using an ergometer attachment and to evaluate swimming performance by this middle power. To perform these purposes, a middle power measurement test in semi-tethered swimming ( STS33 ) using an ergometer attachment was developed.

In STS33, the load of the ergometer attachment was set to 7.0kg and the power measurement interval was set at 5.0 seconds. The subject was instructed to swim at full strength for 33.0 seconds. Power measurements using the ergometer attachment were taken 3 times during the 33.0 seconds at the end of 10s, 20s and 30s respectively. The first measurement ( 1st measured phase ) was taken between 5 and 10 seconds from the start of the swim. The second measurement ( 2nd measured phase ) was taken between 15 and 20 seconds of the swim, and the third measurement ( 3rd measured phase ) was taken between 25 and 30 seconds from the start of the swim by the present investigators.

As in preliminary experiments, the exercise intensity of the STS33 was measured as the average blood lactate concentration produced by the work rate. After each STS33, a blood sample was taken by a licensed nurse under supervision of a medical doctor. Subjects were 5 junior elite swimmers designated to train by the N prefecture Swim Association.

The group mean post exercise blood lactate concentration was 10.5mM/l. These concentration of blood lactate was greater than the OBLA measurement of 4mM for lactate accumulation developing in the middle phase of a swim trial. This result led to the conclusion that the STS33 test could be used to evaluate the middle power.

In a main experiment, 21 male elite junior swimmers were measured. Middle power in swimming in each subject was measured by the above-mentioned STS33 and the relationship between the group mean middle power and group mean total swim time was analyzed. The relationship between the average power (  $P$ : watt ) of the 3 measured phases in STS33 and swimming velocity (  $V$ : m/sec ) in 50m event was  $P = -134.53 + 87.02 V$  (  $r=0.880$ ,  $p < 0.001$  ). The relationship between the average power (  $P$  ) of the 3 phases in STS33 and swimming velocity (  $V$  ) in 100m event was given by  $P = -191.95 + 128.92 V$  (  $r=0.940$ ,  $p < 0.001$  ). From these results, the middle power in STS33 is appropriate for evaluating swimming performances in 50m and 100m events.

Key words : Middle power, Ergometer Attachment, Lactic acid system, Semi-tethered swimming

### Introduction

It is important to evaluate the driving force and attained power in swimming in order to advance the performance of a swimmer. Systems such as the swim-mill or the power processor for swimming ( PPS ) presently available to measure the swimming force or power are very expensive, however, in general.

In previous studies, Shionoya et al. developed<sup>14)</sup> an ergometer attachment for the measurement of power and driving force in swimming and both these indices were measured in the present study

using the system described below. Using an ergometer attachment, driving power was evaluated from the force with which a swimmer pulled on a wire attached to a weight. This type of swimming is called semi-tethered swimming ( STS ). Moriya et al. reported<sup>16)</sup> the relationship between swimming performance and power in STS with an 8.0kg resistance force, in Japanese elite male swimmers using the above-mentioned PPS. Shionoya et al. reported<sup>14)</sup> the relationship between performance and both maximum power and power in STS against 7.0 kg resistance in junior elite swimmers using the ergometer attachment. In addition, Shionoya et al. reported<sup>15)</sup> a large number of power measurements in STS in a short period using several ergometer attachments and proved that power was in proportion to the cube of swimming velocity.

All of the reported power measurements,

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however, were at a high power ( The maximum power ) with power output at maximum effort within 10 seconds in the STS, but middle power ( Sub-maximum power ) exerted in swims of 30 or 40 seconds duration at full effort in STS has not been extensively measured. The purposes of this study are to measure the middle power generated during 30 to 40 seconds of full effort swimming, the energy for which is developed anaerobically at the expense of a mounting blood lactic acid concentration during STS and to evaluate over all performance in swimming by this middle power measurement standard. Power in this study is a driving power with tractioning against some tension in STS.

## Method

### *Setting of the ergometer attachment system*

The ergometer attachment used in this study has been reported in previous studies<sup>14)15)</sup>. The structure and function of the ergometer attachment was referred to in the above studies.

Fig.1 shows an outline of the middle power measurement in STS using the ergometer attachment. In this power measurement, the load of the ergometer attachment was set to 7.0 kgf and the power measurement time was set to 5.0 seconds. The subject was instructed to swim against a 7.0 kg traction of the ergometer at full strength for 33.0 seconds ( STS33 ). The reason why the STS lasted 33.0 seconds was that the energy for middle power development mainly derives anaerobically from an increasing blood lactic acid concentration and the time during which this energy is supplied anaerobically lasts approximately 33.0 seconds. In addition, the subject was instructed to start of swim without kicking to a wall of pool.

Power measurements were made 3 times in the STS33 test. The first measurement of power ( 1st measured phase ) was made between 5 seconds and 10 seconds from the start of the swim, the second measurement ( 2nd measured phase )

was made between 15 and 20 seconds and the third ( 3rd measured phase ) was made between 25 seconds and 30 seconds of the test.

### *Preliminary Experiment*

In a preliminary experiment, to measure exercise metabolic intensity in the STS33 test, blood lactate was measured at defined times. Subjects were 5 junior elite swimmers designated to train by N prefecture Swim Association ( NSA ).

After the STS33, a blood sample was taken from the finger tip of each subject by a licensed nurse under supervision of a medical doctor. Blood lactate was measured by analyzing each blood samples into the automatic lactate analyzer ( YSI. Sports Lactate Analyzer 1500L ). Calibration of the lactate analyzer was made before blood sample analysis using two calibrated liquids the concentration of each of which was already known.

### *The Main Experiment*

Subjects of the main experiment were 21 male junior elite swimmers specializing in the crawl stroke and chosen by the NSA. As mentioned-above, each subject was instructed to swim using a crawl stroke at full strength for 33.0 seconds with a 7.0 kg traction delivered from the ergometer attachment. Power measurements were taken during 3 intervals; 5-10, 15-20 and 25-30 seconds after the start of the swim in each STS33 test for each subject.

Mean power in the STS was evaluated from the power development in the 3 measured phases and presented as average power. This evaluation mirrors to Wingate power test using a cycle ergometer. The Wingate power test evaluates mean power. In addition, the relationship between swimming performance and power in the 3 measured phases and the average power was compared. An index of real swimming performance was made from the swimming velocity calculated from individual swim times recorded in the 50m and 100m crawl stroke of each subject in last

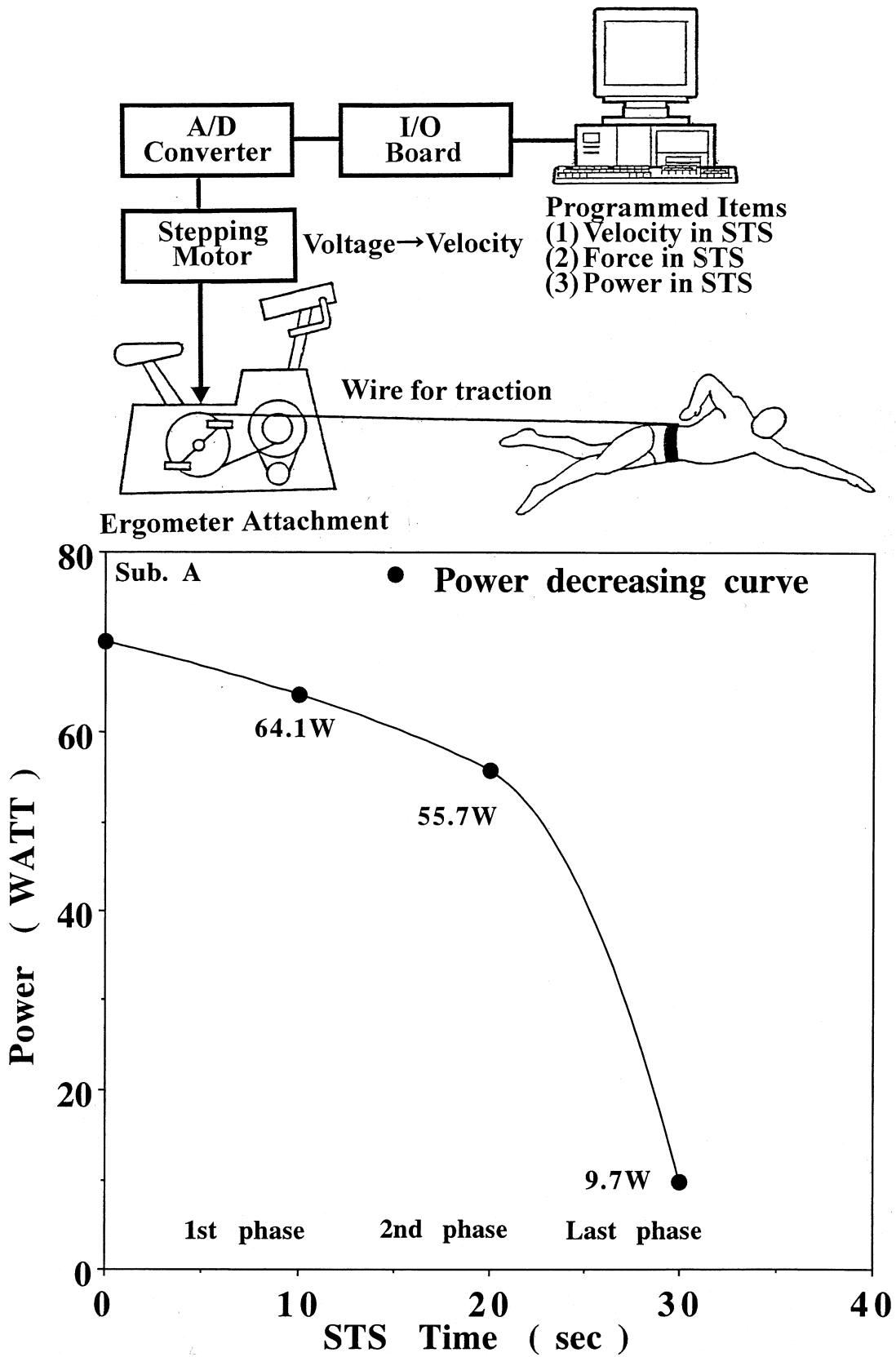


Fig.1 Outline of the middle power measurement in STS. Period between 30 and 33 seconds was for the calculation of power based on the ergometer attachment program.

year. Individual swim times of each subject in last year was referred from the 30th ranking of NSA in last year. 2 subjects ( Subject I, U ) in the 50m and 4 subjects ( Subject E, G, K, O ) in the 100m had no 30th ranking of NSA in last year ( Table.2 ).

## Results

### *Result of the preliminary experiment*

Table.1 shows the results of preliminary experiments. Average power in the 1st measured phase was 45.7 W ( SD=5.2 ), in 2nd phase it was 30.2 W ( SD=9.8 ) and in the 3rd phase it was 13.0 W ( SD=3.6 ), the mean of 3 phases in the STS33 test was 29.6 W ( SD=6.1 ). The mean group blood lactate concentration after the STS33 test was 10.5 mM ( SD=1.3 ).

### *Result of the main experiment*

Table.2 shows the results of the main experiment. Average swimming velocity in the 50m crawl was 1.86 m/sec ( SD=0.08 ) and that in the 100m was 1.71 m/sec ( SD=0.06 ). Average power in the 1st measure phase was 44.5 W ( SD=7.7 ) and in the 2nd was 26.8 W ( SD=11.8 ). Power in 3rd phase was 9.5 W ( SD=5.5 ). The mean decrease in the ratio of power from the 1st to the 2nd measured phase was 41.7 % ( SD=18.2 ) and that from the 1st to the 3rd was 79.1 % ( SD=9.4 ). Average power of the 3 phases ( STS33 ) was 26.9 W ( SD=7.5 ).

Figs. 2, 3, 4, and 5 show the relationships between the power in the STS33 test and swimming velocity in the 50m. The relationship between power in the 1st measured phase ( P ) and swimming velocity ( V ) was  $P = -112.32 + 84.76 V$  (  $r=0.882, p<0.001$  ). The relationship in the 2nd phase was  $P = -221.36 + 133.54 V$  (  $r=0.878, p<0.001$  ), and in 3rd phase was  $P = -72.92 + 44.31 V$  (  $r=0.627, p<0.01$  ). Moreover, the relationship between the average power of the 3 phases in the STS33 test and swimming velocity was  $P = -134.53$

$+ 87.02 V$  (  $r=0.880, p<0.001$  ).

Figs.6, 7, 8 and 9 show the relationship between power in the STS33 test and swimming velocity in the 100m. The relationship between power in the 1st phase ( P ) and swimming velocity in 100m ( V ) was  $P = -147.22 + 113.0 V$  (  $r=0.830, p<0.001$  ). The relationship in 2nd phase was  $P = -292.99 + 188.51 V$  (  $r=0.905, p<0.001$  ), and in 3rd phase was  $P = -135.64 + 85.26 V$  (  $r=0.803, p<0.001$  ). The relationship between the average power ( P ) of the 3 phases in the STS33 test and swimming velocity ( V ) was  $P = -191.95 + 128.92 V$  (  $r=0.940, p<0.001$  ).

## Discussion

There are few systems which measure the mechanical work rate of exercise in water such as in swimming. In existing systems such as the swim-mill, the water flow processor or the power processor for swimming ( PPS ), the equipment is very expensive. Therefore, a swimming ergometer system for the measurement of the mechanical work rate in swimming was developed for the present study.

The ergometer system (ergometer attachment) for swimming has used a tractional swimming against a fixed tension wire as with the PPS. This type of swimming is called resisted swimming. One type of resisted swimming is fully-tethered swimming ( FTS )<sup>1) 2)</sup>, which is tractional swimming without driving forward. Another type is semi-tethered swimming ( STS )<sup>2) 3) 4) 11)</sup> which includes driving forward. The resisted swimming used in the ergometer attachment or PPS is STS.

Until now, when performance in swimming has been evaluated by power, a swim bench test or a Wingate arm test<sup>5) 12) 13)</sup> has been used. Costill and Sharp suggested<sup>3) 4) 13)</sup>, however, that the correlation between performance in swimming and the power measured by these tests was low, because the performance of subjects was almost equal and at a high level in these studies ( Costill, 1985; Sharp, 1986 ).

Moriya proved<sup>9)</sup> the relationship between

Table.1 : Result of preliminary experiment

Subject	Power in 1st phase (WATT)	Power in 2nd phase (WATT)	Power in 3rd phase (WATT)	Averaged Power (WATT)	Blood lactate density (mmol/l)
A	55.0	45.3	18.2	39.5	8.9
B	43.8	26.6	10.5	27.0	10.1
C	38.9	16.8	8.3	21.3	12.5
D	44.7	25.9	12.1	27.6	11.3
E	46.1	36.6	15.8	32.8	9.8
Ave. (SD)	45.7 (5.2)	30.2 (9.8)	13.0 (3.6)	29.6 (6.1)	10.5 (1.3)

Table.2 : Result of main experiment

Sub.	Swim.Velocity in 50m crawl (m/s)	Swim. Velocity in 100m crawl (m/s)	Power in 1st phase (WATT)	Power in 2nd phase (WATT)	Power in 3rd phase (WATT)	Decreasing rate from 1st to 2nd (%)	Decreasing rate from 1st to 3rd (%)	Averaged Power of 3 phases (WATT)
A	2.00	1.82	64.1	55.7	9.7	13.1	84.9	43.2
B	1.93	1.77	55.9	41.9	20.8	25.0	62.8	39.2
C	1.97	1.79	54.8	42.5	21.3	22.4	61.1	39.5
D	1.96	1.81	56.8	49.1	22.6	13.6	60.2	42.8
E	1.82	—	43.3	16.3	5.3	62.4	87.8	21.6
F	1.82	1.69	39.2	24.3	5.3	38.0	86.5	22.9
G	1.90	—	42.9	28.2	10.8	34.3	74.8	27.3
H	1.91	1.73	44.1	25.6	11.7	42.0	73.5	27.1
I	—	1.73	37.3	34.4	13.7	7.8	63.3	28.5
J	1.86	1.69	43.9	16.7	7.5	62.0	82.9	22.7
K	1.79	—	40.7	23.0	10.0	43.5	75.4	25.6
L	1.88	1.65	48.0	29.4	4.6	38.7	90.4	27.3
M	1.87	1.72	47.7	25.3	6.7	47.0	86.0	26.6
N	1.87	1.67	41.8	27.4	7.9	34.6	81.1	25.7
O	1.66	—	29.9	5.3	4.8	82.3	83.1	13.3
P	1.82	1.65	37.4	20.1	6.7	46.3	82.1	21.4
Q	1.85	1.68	42.4	21.8	4.3	48.6	89.9	22.7
R	1.84	1.66	41.2	20.8	6.0	49.5	84.7	22.7
S	1.81	1.66	45.4	14.9	6.3	67.2	86.1	22.2
T	1.76	1.65	39.2	20.1	6.8	48.7	82.4	22.0
U	—	1.65	38.7	20.0	6.7	48.3	82.7	21.8
AVE. (SD)	1.86 (0.08)	1.71 (0.06)	44.5 (7.7)	26.8 (11.8)	9.5 (5.5)	41.7 (18.2)	79.1 (9.4)	26.9 (7.5)

performance in swimming and the power in STS using the PPS. In the former study, the relationship between the load and the power, and the most suitable load for training in STS

remained to be clarified.

As mentioned-above, Shionoya et al. proved<sup>14)</sup> the relationship between performance in swimming and power in STS using the ergometer attachment. The

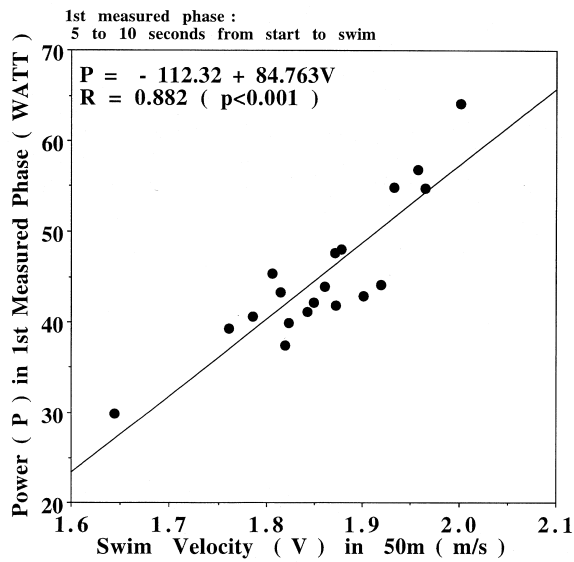


Fig.2 The relationship between power in 1st measured phase in STS33 and swimming velocity in 50m

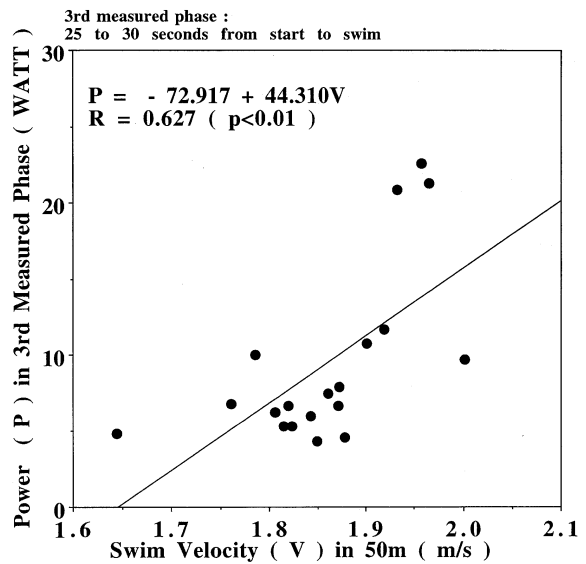


Fig.4 The relationship between power in 3rd measured phase in STS33 and swimming velocity in 50m

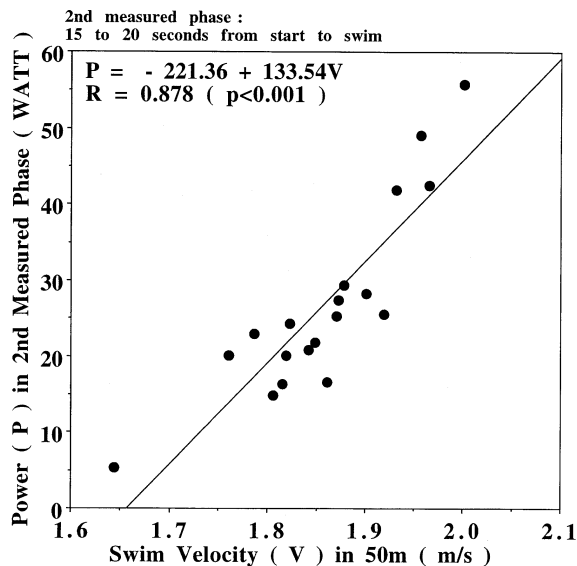


Fig.3 The relationship between power in 2nd measured phase in STS33 and swimming velocity in 50m

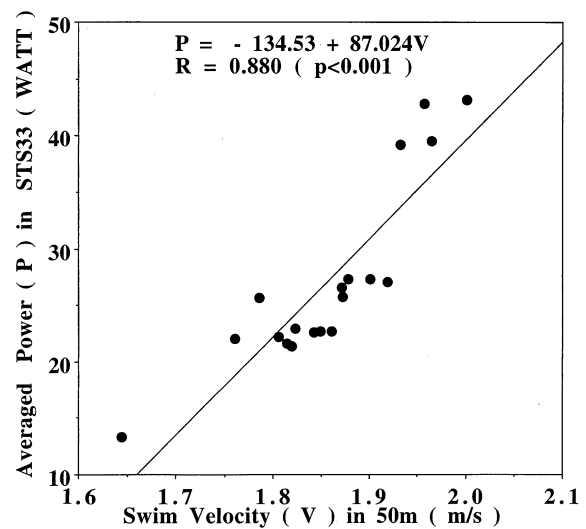


Fig.5 The relationship between power of 3 measured phase in STS33 and swimming velocity in 50m

above investigators made a large number of power measurements of STS using several ergometer attachments and from this results, suggested<sup>15)</sup> that power in swimming was in proportion to the cube of swimming velocity.

However, all of these powers measured by the PPS or the ergometer attachment were conducted at high power (Maximum power) which output was

made for 10 seconds at full effort, energy for which is mainly supplied from the phosphagen system through ATP ( Adenosin triphosphate ) re-synthesis by CP ( Creatine phosphate ). Powers in a human exercise is categorized according to the energy supply system as follows; high power, energy is supplied by the redundant phosphagen system, middle power, energy supported by a

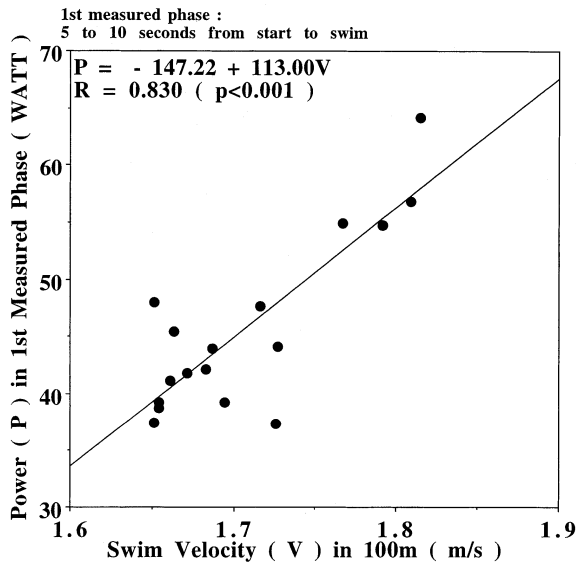


Fig.6 The relationship between power in 1st measured phase in STS33 and swimming velocity in 100m

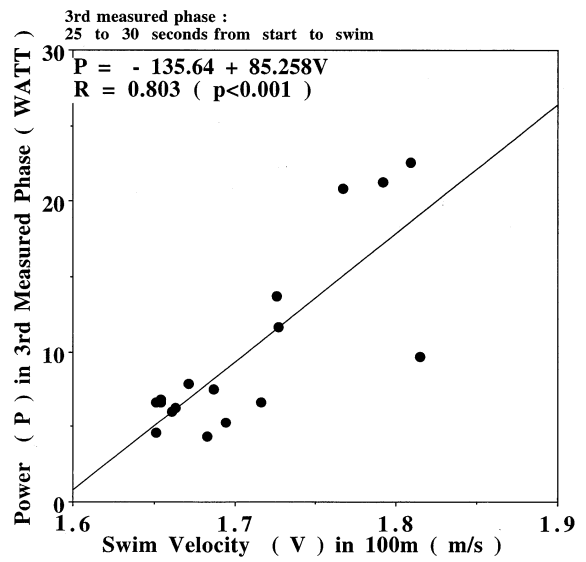


Fig.8 The relationship between power in 3rd measured phase in STS33 and swimming velocity in 100m

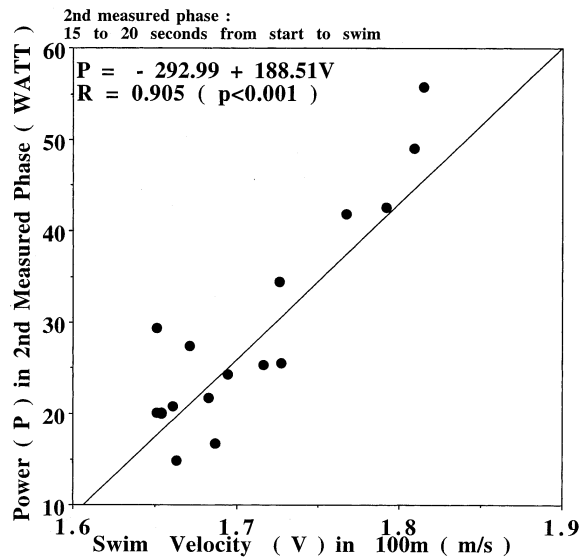


Fig.7 The relationship between power in 2nd measured phase in STS33 and swimming velocity in 100m

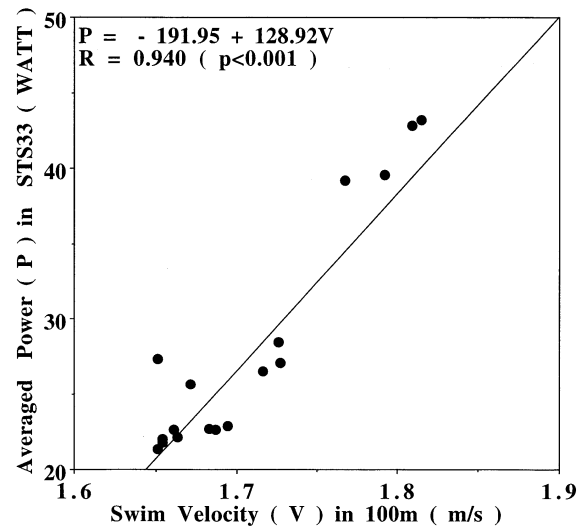


Fig.9 The relationship between power of 3 measured phase in STS33 and swimming velocity in 100m

production of lactic acid through anaerobic glycolysis and low power, energy is supplied by the aerobic system<sup>1)8)</sup>. Until now, high power in swimming has been evaluated using the PPS or the ergometer attachment and low power has been evaluated by the oxygen uptake using a swim-mill. Middle power in swimming, however, has been evaluated very little.

In this study, the evaluation of middle power in swimming was attempted to be evaluated using an ergometer attachment to a swimmer. In preliminary experiment, blood lactate concentration after an STS33 measured an average of 10.5 mM/l. This result led to the conclusion that an STS33 evaluated middle power in swimming because the blood lactate concentration was greater than the



OBLA ( Onset of blood lactate accumulation ) threshold<sup>7)10)</sup>. This proves that the energy in an STS33 test may be applied at an incremental resistance level to require and has supplied additionally from anaerobic glycolysis.

As mentioned-above, fig.2, 3 and 4 show the relationship between performance in a 50m swim and intermediate power output in each measure phases. In every phase, the relationship between performance and power was highly significant. As was the case of in high power tests in the STS which Moriya<sup>9)</sup> and Shionoya<sup>14)</sup> reported.

On the other hand, fig.6, 7 and 8 show the relationships between performance in the 100m and powers in each measure phase. Likewise the 50m, the relationship between performance and power showed high significance in every phase.

Fig.5 shows the relationship between performance and power both during a STS33 test of 50m and fig.9 shows the relationship of these in 100m. Both relationships are highly significant. From these results, middle power in STS33 can be used to evaluate swimming performances in both the 50m and the 100m events.

Comparing the 50m with the 100m, the relationship between performance and power the 100m is somewhat higher than that in the 50m. Holmer reported<sup>6)</sup> a partial energy contribution from both anaerobic and aerobic energy sources in the maximum effort swimming. The present report suggested 90 percent of total energy consumption had been supplied from anaerobic sources in the 50m and 90 percent supplied from the aerobic sources in the 1500m. Wakayoshi pointed out that short-distance swimmers required anaerobic critical power and long-distance swimmers required aerobic power. In fact in present swimming competitions, it is difficult for a swimmer to win both in 100m and 200m events despite both being short-distance events. In the 100m racing, 85 percent of total energy consumption is supplied anaerobically and 15 percent is from aerobically, in the 200m 60 percent is anaerobically and 40 percent is aerobically<sup>16)</sup>.

The 50m crawl takes almost 25 seconds. On the

other hand, the 100m takes almost 50 seconds. As mentioned-above, power in STS reported by Moriya and Shionoya thus far, has evaluated high power output swimming. The power output within 10 seconds ( STS10 ). However, all short-distance swimming ( 50m, 100m and 200m ) takes more than 25 seconds. Therefore, power measurement in STS for the evaluation of swimming performance must extend beyond 30 seconds. And STS33 is better than STS10 for the evaluation of short-distance swimming performance.

In addition, STS33 allows analysis of power output from a number of sources. As note-above, STS33 has 3 measurement phases. Power in the 1st measured phase applies to high power. Therefore, the relationship between performance in the 50m and power in the 1st phase is significant in this study too.

Moreover, power in the 3rd phase together with the average power of 3 phases estimates middle power, and these evaluation procedures replicates the Wingate power test using a cycle ergometer. As mentioned-above, Wingate power test has been performed as an index of the capacity of the lactic acid system. Therefore, the relationship between performance in the 100m and power in the 3rd phase or average power was highly related in this study.

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